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VOLUME VI

SEASAT ECONOMIC ASSESSMENT

ARCTIC OPERATIONS

CASE STUDY AND GENERALIZATION

ECON INCORPORATED

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VOLUME VI
SEASAT ECONOMIC ASSESSMENT
ARCTIC OPERATIONS
CASE STUDY AND GENERALIZATION

Prepared for

National Aeronautics and Space Administration
Washington, D.C.

Contract No. NASW-2558

August 31, 1975

Note of Transmittal

The SEASAT Economic Assessment was performed for the Special Programs Division, Office of Applications, National Aeronautics and Space Administration, under Contract NASW-2558. The work described in this report began in February 1974 and was completed in August 1975.

The economic studies were performed by a team consisting of Battelle Memorial Institute; the Canada Centre for Remote Sensing; ECON, Inc.; the Jet Propulsion Laboratory; and Ocean Data Systems, Inc. ECON, Inc. was responsible for the planning and management of the economic studies and for the development of the models used in the generalization of the results.

This volume presents case studies and generalization concerning the economic benefits of the improved forecasting of ice, sea and weather conditions to operations in the Arctic. The case studies were performed by Battelle Memorial Institute and the Canada Centre for Remote Sensing. C. W. Hamilton managed the case study performed by Battelle. J. C. Henien managed the study performed by the Canada Centre for Remote Sensing. The integration of the case studies was performed by K. Hicks of ECON, Inc.

The SEASAT Users Working Group (now Ocean Dynamics Subcommittee), chaired by J. Apel of the National Oceanographic and Atmospheric Administration, served as a valuable source of information and a forum for the review of these studies. Mr. S.W. McCandless, the SEASAT Program Manager, coordinated the activities of the many organizations that participated in these studies into the effective team that obtained the results described in this report.

B.P. Miller

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This report, consisting of ten volumes, represents the results of the SEASAT Economic Assessment, as completed through August 31, 1975. The individual volumes in this report are:

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Volume	II -	The SEASAT System Description and Performance
Volume	III -	Offshore Oil and Natural Gas Industry - Case Study and Generalization
Volume	IV -	Ocean Mining - Case Study and Generalization
Volume	V -	Coastal Zones - Case Study and Generalization
Volume	VI -	Arctic Operations - Case Study and Generalization
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Each volume is self-contained and fully documents the results in the study area corresponding to the title. Table 1.1 describes the content of each volume to aid readers in the selection of material that is of specific interest.

The SEASAT Economic Assessment began during Fiscal Year 1975. The objectives of the preliminary economic assessment, conducted during Fiscal Year 1975, were to identify the uses and users of the data that could be produced by an operational SEASAT system and to provide preliminary estimates of the benefits produced by the applications of this

Table 1.1: Content and Organization of the Final Report

Volume No.	Title	Content
I	Summary and Conclusions	A summary of benefits and costs, and a statement of the major findings of the assessment.
II	The SEASAT System Description and Performance	A discussion of user requirements, and the system concepts to satisfy these requirements are presented along with a preliminary analysis of the costs of those systems. A description of the plan for the SEASAT data utility studies and a discussion of the preliminary results of the simulation experiments conducted with the objective of quantifying the effects of SEASAT data on numerical forecasting.
III	Offshore Oil and Natural Gas Industry-Case Study and Generalization	The results of case studies which investigate the effects of forecast accuracy on offshore operations in the North Sea, the Celtic Sea, and the Gulf of Mexico are reported. A methodology for generalizing the results to other geographic regions of offshore oil and natural gas exploration and development is described along with an estimate of the world-wide benefits.
IV	Ocean Mining - Case Study and Generalization	The results of a study of the weather sensitive features of the near shore and deep water ocean mining industries are described. Problems with the evaluation of economic benefits for the deep water ocean mining industry are attributed to the relative immaturity and highly proprietary nature of the industry.

Table 1.1. Content and Organization of the Final Report (continued)

Volume No.	Title	Content
V	Coastal Zones - Case Study and Generalization	The study and generalization deal with the economic losses sustained in the U.S. coastal zones for the purpose of quantitatively establishing economic benefits as a consequence of improving the predictive quality of destructive phenomena in U.S. coastal zones. Improved prediction of hurricane landfall and improved experimental knowledge of hurricane seeding are discussed.
VI	Arctic Operations - Case Study and Generalization	The hypothetical development and transportation of Arctic oil and other resources by ice breaking super tanker to the continental East Coast are discussed. SEASAT data will contribute to a more effective transportation operation through the Arctic ice by reducing transportation costs as a consequence of reduced transit time per voyage.
VII	Marine Transportation-Case Study and Generalization	A discussion of the case studies of the potential use of SEASAT ocean condition data in the improved routing of dry cargo ships and tankers. Resulting forecasts could be useful in routing ships around storms, thereby reducing adverse weather damage, time loss, related operations costs, and occasional catastrophic losses.
VIII	Ocean Fishing - Case Study and Generalization	The potential application of SEASAT data with regard to ocean fisheries is discussed in this case study. Tracking fish populations, indirect assistance in forecasting expected populations and assistance to fishing fleets in avoiding costs incurred due to adverse weather through improved ocean conditions forecasts were investigated.
IX	Ports and Harbors - Case Study and Generalization	The case study and generalization quantify benefits made possible through improved weather forecasting resulting from the integration of SEASAT data into local weather forecasts. The major source of avoidable economic losses from inadequate weather forecasting data was shown to be dependent on local precipitation forecasting.
X	A Program for the Evaluation of Operational SEASAT System Costs	A discussion of the SATIL 2 Program which was developed to assist in the evaluation of the costs of operational SEASAT system alternatives. SATIL 2 enables the assessment of the effects of operational requirements, reliability, and time-phased costs of alternative approaches

data.* The preliminary economic assessment identified large potential benefits from the use of SEASAT-produced data in the areas of Arctic operations, marine transportation, and offshore oil and natural gas exploration and development.

During Fiscal Year 1976, the effort was directed toward the confirmation of the benefit estimates in the three previously identified major areas of use of SEASAT data, as well as the estimation of benefits in additional application areas. The confirmation of the benefit estimates in the three major areas of application was accomplished by increasing both the extent of user involvement and the depth of each of the studies. Upon completion of this process of estimation, we have concluded that substantial, firm benefits from the use of operational SEASAT data can be obtained in areas that are extensions of current operations such as marine transportation and offshore oil and natural gas exploration and development. Very large potential benefits from the use of SEASAT data are possible in an area of operations that is now in the planning or conceptual stage, namely the transportation of oil, natural gas, and other resources by surface ship in the Arctic regions. In this case, the benefits are dependent upon the rate of development of the resources that are believed to be in the Arctic regions, and also dependent upon the choice of surface transportation over pipelines as the means of moving these resources to the lower

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*SEASAT Economic Assessment, ECON, Inc., October 1974.

latitudes. Our studies have also identified that large potential benefits may be possible from the use of SEASAT data in support of ocean fishing operations. However, in this case, the size of the sustainable yield of the ocean remains an unanswered question; thus, a conservative viewpoint concerning the size of the benefit should be adopted until the process of biological replenishment is more completely understood.

With the completion of this second year of the SEASAT Economic Assessment, we conclude that the cumulative gross benefits that may be obtained through the use of data from an operational SEASAT system, to provide improved ocean condition and weather forecasts is in the range of $859 million to $2709 million ($1975 at a 10 percent discount rate) from civilian activities. These are gross benefits that are attributable exclusively to the use of SEASAT data products and do not include potential benefits from other possible sources of weather and ocean forecasting that may occur in the same period of time. The economic benefits to U.S. military activities from an operational SEASAT system are not included in these estimates. A separate study of U.S. Navy applications has been conducted under the sponsorship of the Navy Environmental Remote Sensing Coordinating and Advisory Committee. The purpose of this Navy study was to determine the stringency of satellite oceanographic measurements necessary to achieve improvements in

military mission effectiveness in areas where benefits are known to exist.* It is currently planned that the Navy will use SEASAT-A data to quantify benefits in military applications areas. A one-time military benefit of approximately $30 million will be obtained by SEASAT-A, by providing a measurement capability in support of the Department of Defense Mapping, Charting and Geodesy Program.

Preliminary estimates have been made of the costs of an operational SEASAT program that would be capable of producing the data needed to obtain these benefits. The hypothetical operational program used to model the costs of an operational SEASAT system includes SEASAT-A, followed by a number of developmental and operational demonstration flights, with full operational capability commencing in 1985. The cost of the operational SEASAT system through 2000 is estimated to be about $753 million ($1975, 0 percent discount rate) which is the equivalent of $272 million ($1975) at a 10 percent discount rate. It should be noted that this cost does not include the costs of the program's unique ground data handling equipment needed to process, disseminate or utilize the information produced from SEASAT data. Figures 1.1 and 1.2 illustrate the net cumulative SEASAT exclusive benefit stream (benefits less costs) as a

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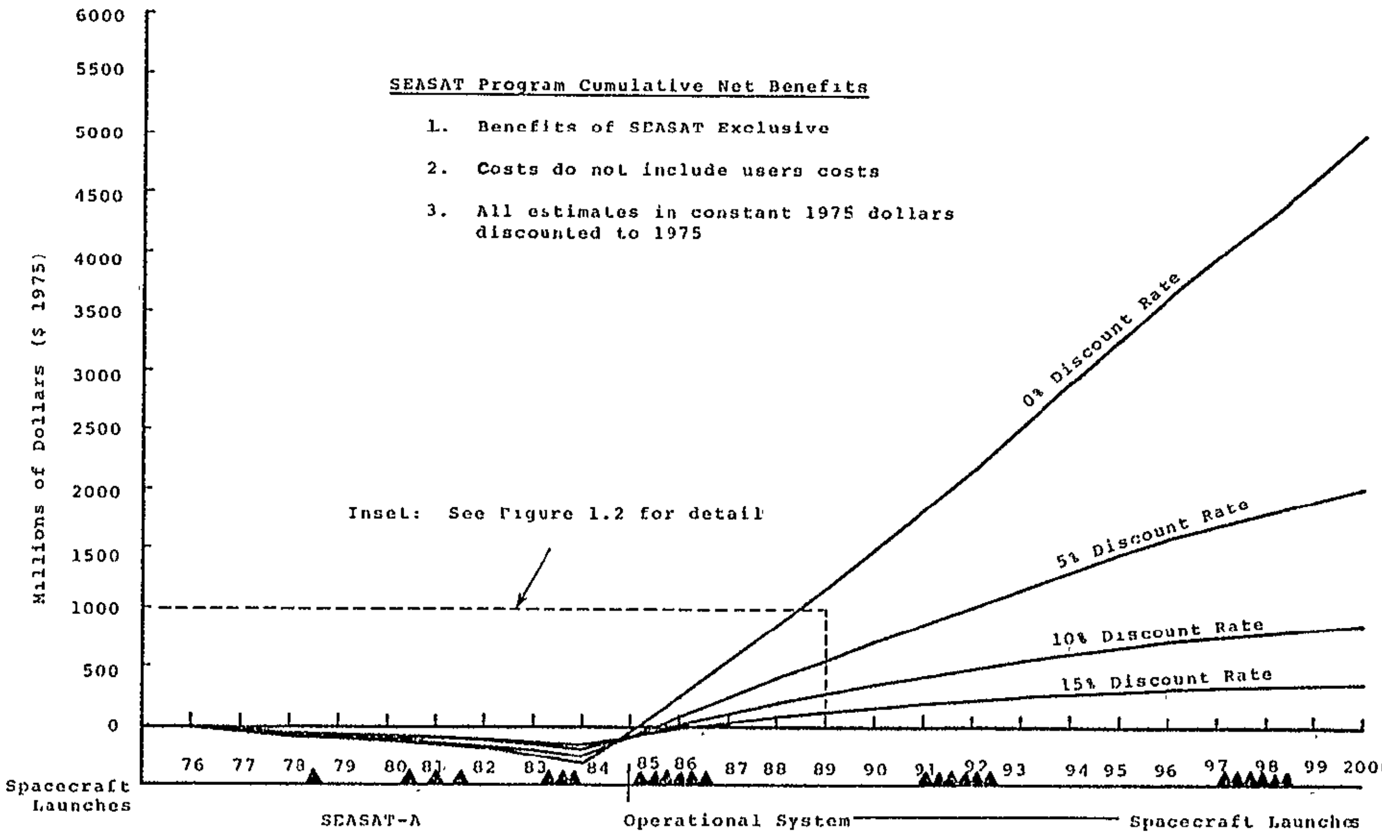
*"Specifications of Stringency of Satellite Oceanographic Measurements for Improvement of Navy Mission Effectiveness." (Draft Report.) Navy Remote Sensing Coordinating and Advisory Committee, May 1975.



Costs*	19	49	78	100	123	151	184	239	307	352	368	373	375	393	437	503	546	566	568	587	629	695	738	753
Benefits*										311	622	933	1244	1555	1937	2319	2701	3083	3465	3847	4229	4611	5375	5757

*Cumulative Costs and Benefits at
0% Discount Rate (millions, $ 1975)

Figure 1.1 SEASAT Program Net Benefits, 1975-2000

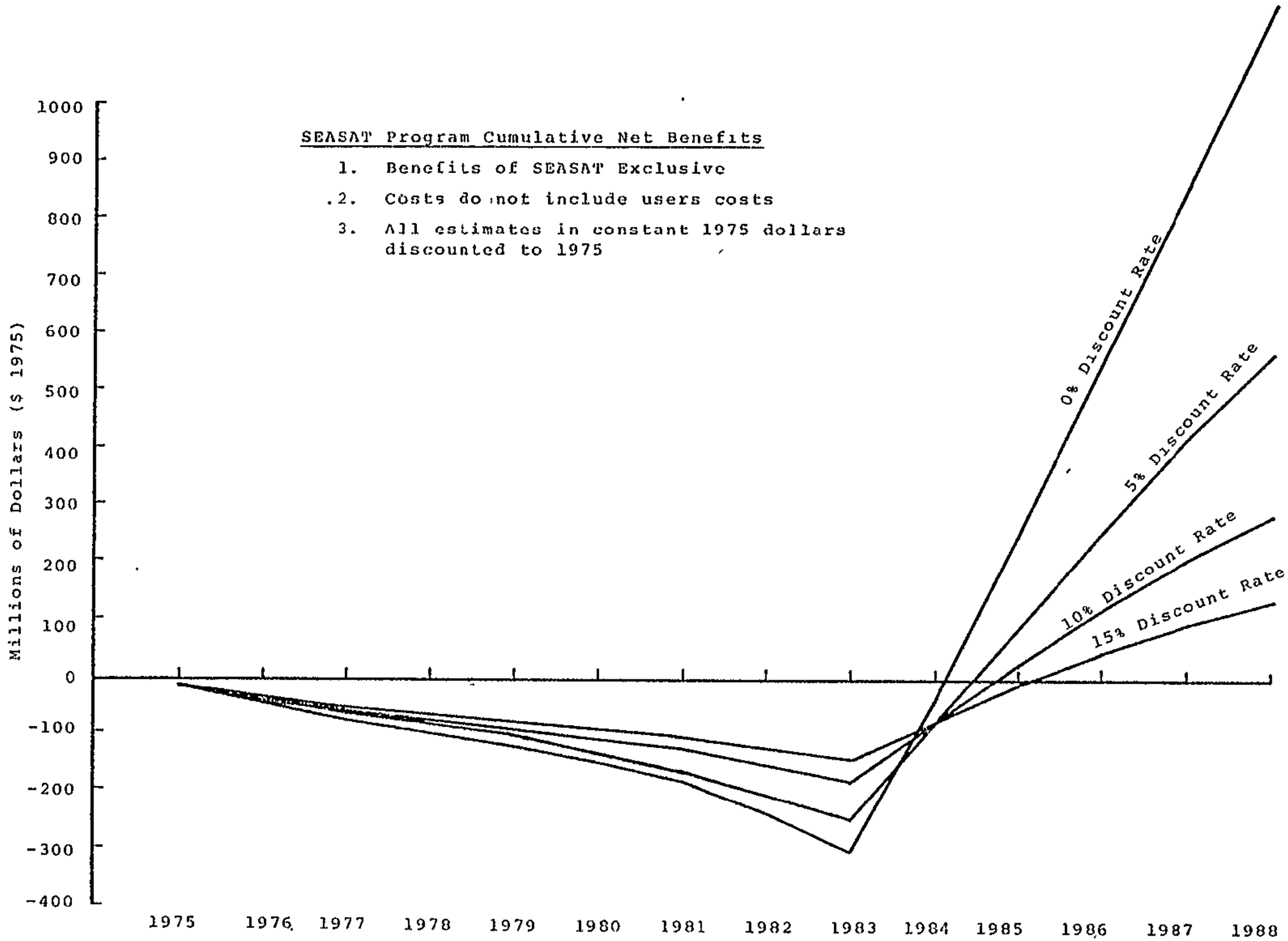


Figure 1.2 SEASAT Program Net Benefits
(Inset from Figure 1.1)

function of the discount rate.

This volume describes the results of the case studies of the economic benefits of improved forecasts of ice, weather and ocean conditions to operations in the Arctic.

2. ICE RECONNAISSANCE OF THE ARCTIC NORTHWEST PASSAGE CASE STUDY AND GENERALIZATION

2.1 Overview

This case study is developed on the hypothesis that future significant finds of oil and gas and their production will be made in the North American Arctic regions. It is assumed that some of the produced resources from either the United States or Canadian Arctic will be transported by an ice-breaking Arctic super tanker fleet to the continental East Coast, beginning in 1991 or 1992.

The super tankers will have to transit the Arctic Northwest Passage and in so doing, it is assumed that their movement will be facilitated by SEASAT's observational data that portrays leads through the ice of the passage.

SEASAT data will then contribute to a more effective transportation operation by reducing the transportation costs as a consequence of reduced transit time per voyage.

The effectiveness improvement assumes that the sea ice always contains leads or weaknesses that, if found, can facilitate the tanker transits, and that SEASAT can reliably contribute to identifying these leads or weaknesses for ship navigation purposes.

Depending on the actual contribution of SEASAT to ice lead identification, some fraction of the transit

time reduction savings is directly attributable to the presence of SEASAT.

This application of SEASAT data is very specialized, both spatially and with respect to the location of the resources and to the time of their availability. It is not therefore susceptible to generalization.

The reduction in transportation costs are considered, in part, to be benefits to SEASAT. Although Canada, the United States and the USSR have experimented with ice-breaking operations in the Arctic, the total operation being considered is one that does not currently exist except possibly in concept. The derived benefits are therefore conjectural, possibly speculative, although reasonable.

The content of the case study is therefore directed to the establishment of the reasonableness of the proposed operation, in terms of what is currently known and the trends of that knowledge, as well as to the quantification of the benefits.

3. SUMMARY

A certain undefined possibility exists that from 1992 to 2000* oil and gas from the Alaskan North Slope or the more general North American Arctic region may be shipped by tanker to the continental East Coast. This possibility arises from assumptions that there will be a concentrated effort to develop and produce Arctic oil by the oil concerns of the United States and Canada to reestablish dwindling reserves and satisfy demand in each country. It is also assumed, based on the MARAD study,** that it will be more economical and ecologically sound to operate a fleet of tankers rather than construct a continental pipeline to transport oil to the East Coast to offset the East Coast demand for imported oil.

Accepting these assumptions requires that a fleet of tankers, over the nine or ten years from 1990-2000, carry resources via the Arctic Northwest Passage through the ice, an activity requiring many transits of the passage over the time period of interest.

SEASAT's Synthetic Aperture Radar (SAR) is then visualized as having the capability of providing appropriate

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*The year 2000 is considered to be the horizon for the computation of SEASAT benefits. The life of the extractable resources will probably extend beyond this date.

**ECON, Inc. MARAD: Five Forecast. Report prepared for the Maritime Administration, Washington, D. C., February 1976.

imagery data which will aid in facilitating the transit of the tankers through the ice by providing navigational data and prediction data. Other SEASAT sensors will also aid by providing data for improved weather and ocean condition forecasts.

As a consequence of this capability, the time to transit will be reduced and operating tanker costs will be reduced for each transit. The savings of operating costs, subsequently described as benefits, are estimated to range annually from $178 million to $646 million.

Based on judgmental estimates which attempt to relate the SAR expected capability in 1990-2000 with the requirements for ice navigation in that time, approximately 36 percent of this annual benefit is determined to be exclusively attributable to the presence of SEASAT's orbiting instrumentation and information dissemination system. Thus, the annual benefit exclusive to SEASAT is estimated to range from $64 million to $233 million.

The integrated benefit exclusive to SEASAT over the time period of interest is then calculated as shown below, as a function of discount rate.

Discount rate %	0	5	10	15
Integrated benefit ($ millions 1975)	635 - 2147	248 - 770	96 - 288	39 - 114

It is to be emphasized that the benefits developed are purely hypothetical and concern both oil not yet completely discovered and an operation that is only a concept. In general however, the assumptions are reasonable even though hypothetical; and if the scenario for development of the Arctic resources considered as the basis for this report is reasonably accurate, the benefit estimates derived are also reasonable.

Clearly, the actuality of the benefits depends heavily on political, financial, economic, legal and ecological constraints, the resolution of which cannot at this time be foreseen. It is also not clear that tanker transportation would be cheaper than that of a transcontinental pipeline; however, that tradeoff is not considered to be a part of this study.

The oil and gas under consideration for transportation are expensive resources because of the severe climate of the environment in which they are situated. There is a need to successfully develop technology and techniques for operating in this environment to find and produce the oil and gas and appropriate reserves necessary for economically viable production and transportation to the markets that will be available.

It is estimated by U.S. Geological Survey (USGS) and private industry that there are still significant oil reserves in the continental United States or its offshore

extensions although agreement on the amount is not generally found. In Canada, the principle reserves appear to exist in the Canadian Arctic, a fact which will provide impetus to Canadian Arctic development.

Financing and risk, governmental participation, taxation rules, etc. and the general national policies, that may be evolved to stimulate investment in Arctic exploration, can be expected to generate developmental movement if they are favorable in terms of expected profit to the operators involved. Today, the force of appropriate stimulus to full-scale development is not apparent. Only tentative action which gathers data as a basis for future development is clearly observable.

4. CASE STUDY BACKGROUND AND BASIS

4.1 Introduction

The Case Study Background and Basis presents information which illustrates the need to find new reserves of oil and gas which also leaves in doubt the most advantageous regions for prospecting as a result of estimation of these reserves.

The basis also presents the character of the ice and its variation that must be transmitted by ice-breaking tankers, and the relationship of SEASAT technology to facilitating the problems of navigation for such tanker transits. An estimate is also made of the exclusive contribution that SEASAT may make to easing this difficult navigational problem, from imagery provided by the SAR.

4.2 Oil and Gas Data

Oil data such as that shown in Figure 4.1 indicates a decline in U.S. oil production, an increase in petroleum product consumption and the current status of U.S. oil reserves. Reserves in 1973, including 9.6 billion barrels in the Alaskan North Slope, were 363 billion barrels, down by 1.7 billion barrels from 1972, so that U.S. oil reserves are steadily declining.

In 1973 the proved reserves of natural gas were 266 trillion cubic feet, down from 1972 by 12.7 trillion cubic feet. These reserves include the 26 trillion cubic feet in the Alaskan North Slope.

Reserves, Production

NORTH AMERICA	CRUDE OIL						NATURAL GAS					
	Reserves		Production				Reserves		Production			
	January 1, 1974		1973		1972		January 1, 1974		1973		1972	
	10^6B	10^6T	10^3B/D	10^6T/Y	10^3B/D	10^6T/Y	10^9cu m	10^9cu ft	10^6cu m/y	10^6cu ft/y	10^6cu m/y	10^6cu ft/y
Canada	9,424	1,274	1,798.0	88.7	1,535.0	75.7	1,424	50,299*	91,787	3,241,400	81,023	2,861,300
United States	35,300	4,770	9,189.0	453.2	9,451.0	466.1	7,078	249,950	647,157	22,854,000	648,374	22,897,000
TOTAL	44,724	6,044	10,987.0	541.9	10,986.0	541.8	8,502	300,249	738,944	26,095,400	729,397	25,758,300

*does not include Arctic gas

Source: IPE, 1974, p. 309

Oil Production

NORTH AMERICA	1940	1950	1955	1960	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973*
Canada	23.5**	79.6	354.7	525.6	752.4	801.4	878.4	1,107.0	1,039.0	1,123.6	1,263.6	1,350.0	1,535.0	1,798.0
	1.2***	3.9	17.5	25.9	37.1	29.5	43.3	54.6	51.2	55.4	62.3	66.6	75.7	88.7
United States	3,707.4	5,407.1	6,806.7	7,054.6	7,635.1	7,804.1	8,295.2	10,222.0	10,948.0	9,214.1	8,630.0	9,529.0	9,451.0	9,189.0
	182.8	266.7	335.7	317.9	376.6	384.9	409.1	504.1	540.0	454.4	425.6	470.0	466.1	453.2

* 1973 preliminary; ** per 1,000 b/d; *** per million t/y

Source: IPE, 1974, p. 306

Petroleum Product Consumption

NORTH AMERICA	1940	1950	1955	1960	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973*
Canada	146**	324	548	841	1,050	1,142	1,205	1,251	1,348	1,418	1,525	1,531	1,665	1,755
	7.2***	16.0	27.0	41.4	51.8	56.3	59.4	61.7	66.5	70.0	75.2	75.5	82.1	86.6
United States	3,655	5,780	7,216	9,688	10,846	11,305	11,851	12,562	13,431	14,138	14,350	14,830	15,980	16,814
	180.3	285.1	355.9	477.8	534.9	557.6	584.5	619.6	662.4	697.3	707.7	731.4	788.1	829.3

* 1973 estimated; ** 1,000 b/d; *** million t/y

Source: IPE, 1974, p. 343

Figure 4.1 Reserves and Production Summary

The 1974 International Petroleum Encyclopedia, p. 142, estimates the ultimate recovery in the United States of crude oil from proved reservoirs as well as depleted reservoirs at 136.2 billion barrels.

Continental U.S. exploration has not been very successful in developing reserves. During 1972, for example, new national discoveries only registered 123 million barrels of oil. They contained probable ultimate reserves of 585 million barrels of oil and condensate and 5 trillion cubic feet of gas.* In 1972, 566 new field discoveries were made, an increase of 30.5 percent from 1971 but only 19.4 percent were significant, containing more than 1 million barrels of oil or a gas equivalent (6 billion cubic feet).

The Canadian Petroleum Association reports similarly. In 1973 proved reserve of crude oil and condensates declined by 4.3 percent to 9.2 billion barrels. Crude oil reserves dropped by 3.7 percent to 8 billion barrels, following declines in 1970 of 0.7 percent and 2.6 percent in 1971. Similar declines are indicated for Canadian natural gas.

Recent USGS estimates indicate that the U.S. continental shelf may contain 160 to 190 billion barrels of oil and 820 to 1110 trillion cubic feet of gas that may be recoverable, one quarter of which is estimated to be in the offshore Atlantic. Offshore California is estimated to contain from 6 to 19 billion

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*IPE, 1974, p. 154.

barrels of oil and 12 to 38 trillion cubic feet of gas.*

Figure 4.2, U.S. Petroleum and Natural Gas Resources, shows a composite breakdown by the USGS of these resources.

Future oil and gas demand in both the United States and Canada is difficult to predict. This is particularly so for the time period 1985-2000 under the impetus of policies of self-sufficiency in energy which will develop energy alternatives and seek to conserve petroleum products demand.

In the United States, demand has been stated as slowing from 6-7 percent per annum to 2-4 percent per annum, and in Canada, demand is expected to increase by at least 4.4 percent per annum.**

Canadian output cannot keep pace with these demand estimates, and the United States needs new resource reserves to provide security to its petroleum base.

Explorations to date in the Atlantic offshore and the new Gulf Coast regions have not been successful, and the California offshore explorations have been slowed by the actions of those concerned with ecology.

Inspired by the Prudhoe Bay discovery in Alaska in 1968, United States and Canadian petroleum industries are consequently moving to exploit the costly oil and gas reserves estimated to exist in the North American Arctic. The Prudhoe

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*Offshore, February 1975, p. 231.

**IPE, 1974, p. 247.

U.S. PETROLEUM AND NATURAL GAS RESOURCES

(onshore and offshore to water depth of 200 meters)
Source: U.S. Geological Survey

AREA	PRODUCTION 1972		PRODUCTION Cumulative and 1972		RESERVES Measured***		RESERVES Indicated-Inferred		RESOURCES** Undiscovered Recoverable	
	State	Federal	State	Federal	State	Federal*	State	Federal*	State	Federal
Crude Oil and Natural Gas Liquids (billions of barrels)										
Conterminous states onshore	3.100	0.214	104.200	5.577	29.3	1.7	16.0 - 27.0	1.0 - 1.5	100 - 200	10 - 20
Alaska onshore	0.000	0.009	0.000	0.134	9.6	0.1	5.0 - 10.0	0.0	20 - 40	5 - 10
Total onshore	3.100	0.223	104.200	5.711	38.9	1.8	21.0 - 37.0	1.0 - 1.5	120 - 240	15 - 30
Atlantic offshore	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	2 - 4	8 - 16
Gulf of Mexico offshore	0.100	0.390	0.700	2.770	0.5	3.5	0 - 0.5	2.0 - 3.0	2 - 4	18 - 36
Pacific offshore	0.100	0.020	1.300	0.090	0.7	2.2	0 - 0.5	1.0 - 2.0	1 - 2	4 - 8
Alaska offshore	0.100	0.000	0.500	0.000	0.7	0.0	0 - 0.5	0.0	2 - 4	28 - 56
Total offshore	0.300	0.410	2.500	2.860	1.9	5.7	0 - 1.5	3.0 - 5.0	7 - 14	58 - 116
Total on- and offshore	3.400	0.630	106.700	8.570	40.8	7.5	21.0 - 38.5	4.0 - 6.5	127 - 254	73 - 146
Natural Gas (trillions of cubic feet)										
Conterminous states onshore	17.700	1.001	397.400	16.870	175.7	14.1	86.0 - 164.0	7.0 - 13.0	450 - 900	50 - 100
Alaska onshore	0.00	0.056	0.000	0.307	26.4	2.1	13.0 - 26.0	1.0 - 2.0	80 - 160	25 - 50
Total onshore	17.700	1.057	397.400	17.177	202.1	16.2	99.0 - 190.0	8.0 - 15.0	530 -1060	75 - 150
Atlantic offshore	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	5 - 10	50 - 100
Gulf of Mexico offshore	1.600	3.030	3.900	17.400	6.5	36.8	3.0 - 5.0	18.0 - 36.0	10 - 20	150 - 300
Pacific offshore	0.000	0.010	1.200	0.040	0.7	2.0	0.0 - 0.5	1.0 - 2.0	5 - 10	5 - 10
Alaska offshore	0.100	0.000	0.600	0.000	1.8	0.0	1.0 - 1.5	0.0	20 - 40	150 - 300
Total offshore	0.700	3.040	5.700	17.440	9.0	38.8	4.0 - 7.0	19.0 - 38.0	40 - 80	355 - 710
Total on- and offshore	18.400	4.100	403.100	34.617	211.1	55.0	103.0 - 197.0	27.0 - 53.0	570 -1140	430 - 860

*Distribution between State and Federal is based on assumption that reserves are in the same ratio between the two as recent production.
**As shown by the range, unit figures have little significance for individual areas, but merely show the approximate distribution of the rounded total for the United States - 200-400 billion barrels of petroleum liquids and 1,000-2,000 trillion cubic feet of natural gas.
***Total U.S. measured reserves derived from American Petroleum Institute and American Gas Association.

MEASURED RESERVES are identified resources from which an energy or mineral commodity can be economically extracted with existing technology, and whose location, quality, and quantity are known from geological and engineering evidence.

INDICATED RESERVES are reserves based partly upon specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence.

INFERRED RESERVES are the reserves based upon broad geologic knowledge for which quantitative measurements are not available. Such reserves are estimated to be recoverable in the future as a result of extensions, revisions of estimates, and deeper drilling in known fields.)

(RESOURCES include undiscovered deposits of the same quality as reserves as well as deposits presently unrecoverable for either economic, technologic, or legal reasons.)

Source: The World Almanac, 1975, p. 116; Publisher: Newspaper Enterprise Associatons, Inc., New York, Cleveland.

Figure 4.2 U.S. Petroleum and Natural Gas Resources

field has an estimated reserve of about 10 billion barrels and its oil is destined for U.S. West Coast distribution subsequent to 1977. So far, Canadian exploration in the Mackenzie Delta and the Arctic Islands, in spite of a score of oil and gas strikes, has not yielded a find as substantial as that of the Prudhoe Bay.

Alaska's potentially recoverable reserves are estimated at 40 billion barrels of oil and 300 trillion cubic feet of gas. Geologists identify the exploratory Canadian Arctic regions as the Baffin Shelf, the northern part of Hudson Bay, the Northwest Territories, the Yukon mainland, the Beaufort Basin and the Arctic Islands. Combined, these areas are believed to hold 72 billion barrels of oil and 530 trillion cubic feet of gas with more than 80 percent allocated to the Beaufort Basin and Arctic Islands. Thus, the prize in the Northern American Arctic is some 112 billion barrels of oil and some 830 trillion cubic feet of gas which has to be found and produced.*

A great deal of costly and time-consuming work remains to be done, however, in exploration, development and transportation before any of these products can be marketed. The rapidity and the extent with which access to these resources can be achieved depends on technology, manpower availability, drilling rig availability, costs, prices, capital, government policies and influences exerted with respect to pollution, ecology and

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*<u>IPE</u>, 1974, p. 242.

preservation of the natural environment.

Some opinions of one expert* in Arctic offshore oil activities are quoted below.** These opinions indicate times for maximum oil production in shallow waters from 8 to 12 years, in deeper waters from 16 to 21 years, all using the Prudhoe Bay region as an operating base. More remote regions would have longer timetables.

The near shore area up to about 60 feet of water, Hudson said, offers opportunity for early development because a large portion can be directionally drilled from shore or from existing islands using proven, Arctic, dry land drilling techniques.

Shallow water areas that are out of reach of shore-based directional drilling could be drilled within three years, Hudson said, using technology gained from actual offshore installations in Canada and Alaska's Cook Inlet, and from ongoing research. According to Hudson, an estimated timetable for developing oil production in shallow water in the vicinity of an existing oil field such as Prudhoe Bay, with logistic support facilities and oil transportation system, will follow.

4.2.1 Probable Schedule

The following schedule outlines the basic development stages which the oil industry will most probably adhere to in

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*Hudson, Thomas A., a specialist in Arctic on and offshore R&D engineering.

**Offshore, March 1975, pp. 54, 56.

their efforts toward maximum oil production:

Probable Schedule for Shallow Water

• Environmental Impact Statement	
develop data, hold hearings and prepare report	one year
• Lease Bids	
geophysical, publicize, evaluations	one year
• Exploratory Drilling-System-Design and Fabrication	
from onshore and existing islands	now available
from offshore	three years
• Exploratory Drilling	two years
design, fabricate and install	
from onshore	one year
from offshore	two years
• Development Drilling	
develop first oil production	one year
develop maximum oil production	three years

According to this plan for oil development, it will be six to ten years before the first oil is produced and eight to 12 years until maximum oil production is accomplished.

Probable Schedule for Deeper Water--60 to 200 Feet

• Research and Development	
environmental, sea, ice, soils, etc.	five to ten years
• Environmental Impact Statement	
develop data, hold hearings and prepare report	one year
• Exploratory Drilling-System-Design and Fabrication	three years
• Exploratory Drilling	two years

- Development and Production Structure

  design, fabricate and install — two years

- Development Drilling

  to develop first oil production — one year
  to develop maximum oil production — three years

The total time anticipated to produce the first oil is 14 to 19 years and 6 to 21 years for maximum oil production.

Hudson stressed that estimated times are approximate and will most likely be longer rather than shorter. He said, discoveries in Arctic areas remote from Prudhoe Bay would require several more years beyond that shown in order to research, engineer and build a crude oil transportation system utilizing ice-breaking techniques or under ice transport technology.

Much research remains to be done to prepare the way for the move into offshore Arctic waters. Hudson said, the main gaps in Arctic offshore knowledge relate to sea ice and subsea soil properties.

Describing sea ice as the biggest force on an offshore structure, Hudson said, its strength depends on several factors such as temperature, salinity and load rate and that these are not related to one another. Additionally, sea ice exists in many different shapes and sizes including normal one-year sheet ice, 12 feet thick and greater, pack ice, pressure ridges and ice islands.

Specific research, Hudson added, should be directed to behavior, motion and forms of sea ice in areas of offshore

interest. Continuing work with structural models in ice should be performed in the laboratory and eventually should be performed with larger models in the field. With data from these experiments, mathematical models can be prepared which could be utilized to predict ice forces for other Arctic locations, water depths or structure configurations.

4.2.2 Other Factors Affecting the Schedule of Exploration and Development

Regarding the sea floor, Hudson said, permafrost represents the largest unknown. He said, it is evident that it does exist in shallow waters and perhaps exists in deeper waters. More research is necessary in deeper waters to determine where it exists and what its properties are, also, what happens if permafrost thaws. Also, research is needed to develop a tool to find and map permafrost.

Of the industry's present capability, Hudson said, it has been proven to build artificial islands in shallow water but that depth limit for such islands is around 60 feet.

Depending on the character of the sea ice, exploratory drilling can also be done from the ice sheet itself. Off Prudhoe Bay, he said, is probably limited to shallow water under 60 feet deep.

Exploratory drilling can also be done from a concrete or steel barge, strengthened and with sides sloped for ice resistance. The barge would be ballasted down to rest on the ocean floor. Piling would be installed to hold the barge against

lateral forces. This concept is probably economical now, Hudson said, for very shallow water, 10 to 20 feet deep. While the concept is not proven, it is within the present design capability, he added.

Steel or concrete fabricated gravity structures or pile supported structures are also within present design capability though not yet proven by actual practice. Present design capability is probably limited to about 60 feet of water. Hudson said the structures probably have sloped sides like a cone or a pyramid or they could be of the monopod type. They would have an advantage in exploratory drilling over filled islands because of their mobility. Though not yet proven, he said, such concepts are within present day design capability.

Seasonal methods such as ice-strengthened floating drilling vessels are also within the capability of present technology. Their limitations are economic and relate to degree of ice coverage rather than water depth.

Hudson estimated that the industry could extend its design capability to 100 feet of water after about five years and to 200 feet after ten years of active research and development. The estimate assumes simultaneous drilling on shallow water leases.

Drilling in the Beaufort Sea has been stated as representing a reasonable gamble using present day technology. This sea and adjacent coastal regions are thought to contain 10 billion barrels of recoverable oil and 75 trillion cubic

feet of gas. Subsequent to a $5 million environmental study, drilling will start in summer 1976 using two drillships, 80 percent financed by the industry, the remainder by the federal government. Even with the most ideal exploratory progress re-sults are not contemplated until 1985. Estimates of costs for a specialized drilling unit are about $70 million and the cost of a well at $10 million for four to five times the cost of land-based Arctic exploration.*

If exploration in shallow water is more likely in nine years (1976-1985), rather than three years, production would not come into being until after 14 to 18 years, i.e., 1990 to 1994. The Beaufort Sea region of exploration is shown on the accompanying map of Alaska (Figure 4.3).

Imperial Oils' discovery (Ivik J26) is one of three fields found with total reserves in excess of 5 billion barrels, a volume regarded as an absolute minimum for development and transportation to market from the Arctic.** For natural gas the economic discovery threshold is about 30 trillion cubic feet.

Oil and gas transportation from the Arctic regions have undergone considerable study with the Alyeska project now nearing completion from Prudhoe Bay. Transportation methods are by pipeline proposals briefly summarized in the following paragraphs.

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*Offshore, March 1975, pp. 128, 130.

**Offshore, February 1975, p. 208.

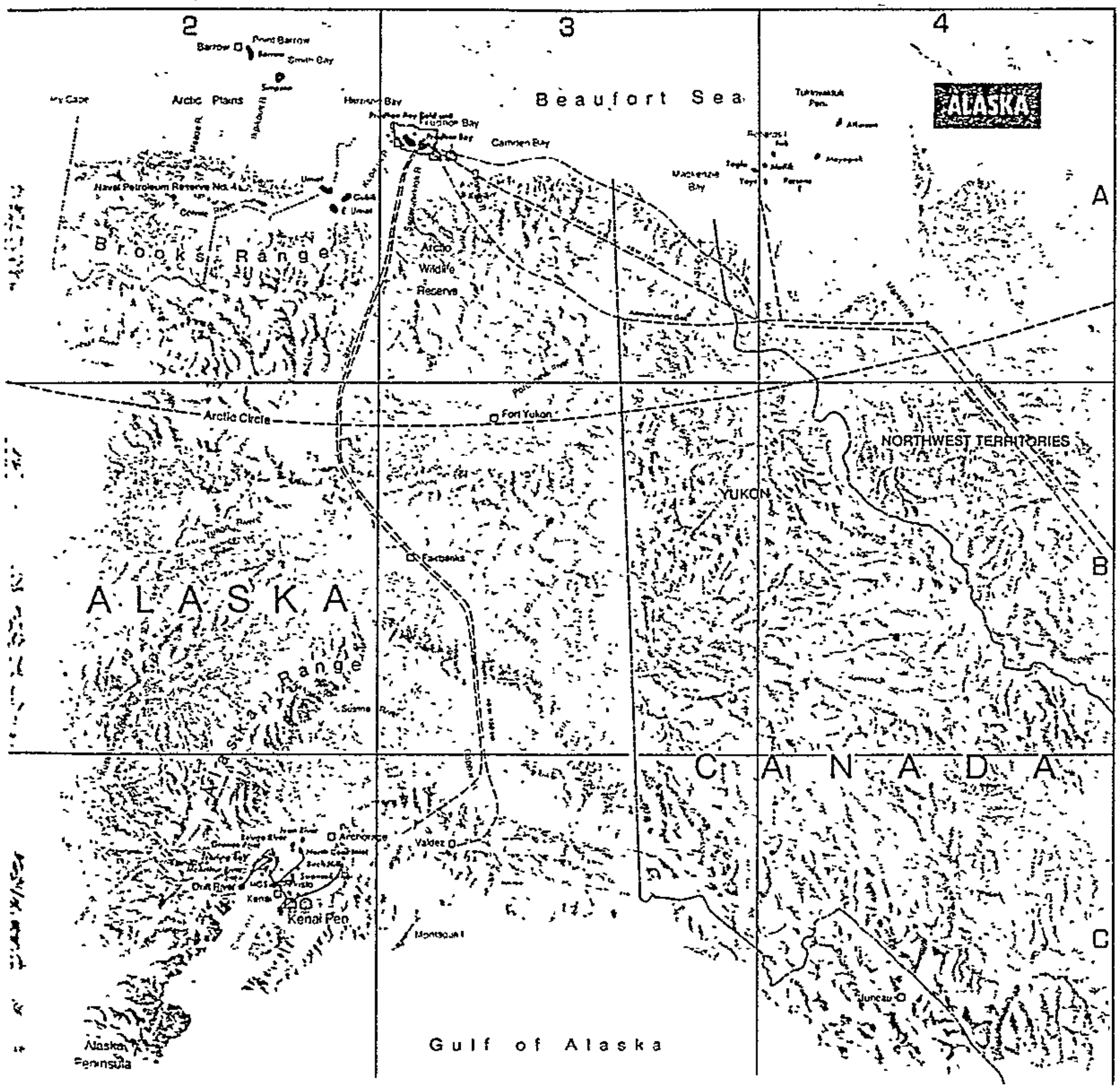

Figure 4.3 Map of Alaska

Engineering and environmental studies have yet to turn up any technical problems that would bar laying big-inch pipelines to move Arctic oil and gas to markets in Canada and the United States.

That is the belief of sponsors of the studies for land and marine pipeline projects on the North Slope, the Mackenzie Delta and in the Arctic Islands. Five pipelines from the Arctic region are proposed by U.S. and Canadian companies at a cost of more than $20 billion. The projects are planned by:

- Alyeska Pipeline Service Company, a seven-company consortium which in January 1974 won final approval from the U.S. government for a 789-mile, 48-inch, $5 billion crude oil line from Prudhoe Bay south, to Alaska's ice-free port of Valdez. Tanker shipments from Valdez to the Lower 48 West Coast are planned in 1977.
- El Paso Natural Gas Company, conducting studies for a natural gas line from Prudhoe Bay field to the southern coast of Alaska where gas would be liquefied for tanker shipment to the Lower 48. Line construction in the $3 billion project would be timed to follow completion of the Alyeska system.

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*IPE, 1974, p. 245.

- Canadian Arctic Gas Study Ltd. (Cagsl), a 27-member consortium planning a $5.5 billion gas line from Prudhoe Bay and the Mackenzie Delta to Monchy, Saskatchewan, via the Mackenzie River Valley.
- Mackenzie Valley Pipe Line Research Ltd., a consortium of 12 companies proposing a $3.4 billion crude oil line that roughly parallels the Cagsl route. The line would connect at Edmonton, Alberta with existing systems of Interprovincial Pipe Line Company and Trans Mountain Oil Pipe Line Company Ltd.
- Polar Gas Project, a six-company group that wants to lay a $5 billion gas line from the Arctic Islands down either side of Hudson Bay to southeastern Canada.

In addition, the U.S. Navy wants to develop oil reserves it holds in Naval Petroleum Reserve No. 4 in northern Alaska and lay its own pipeline system to the state's southern shore. This proposal has not yet reached the firm stage and requires funding by Congress for exploratory drilling.

Oil industry officials believe it is likely that the Mackenzie Valley crude line proposal will be deferred for many years. They base this view on preference for the Alyeska proposal by operators at Prudhoe Bay, the field that holds the vast majority of the Arctic's proved oil reserves.

El Paso and Cagsl were competing for Prudhoe Bay gas supplies. It appeared certain that if El Paso wins, the Cagsl project would be delayed several years until the Mackenzie Delta develops enough reserves to support a big-inch system on its own.

A map of the Arctic Islands is shown in Figure 4.4.

The Prudhoe Bay production is planned at 0.6 million barrels per day by July or August 1977, increasing in capacity to 1.2 million barrels per day by November 1977 with an ultimate capacity of 2 million barrels per day but a throughput of 1.6 to 1.7 million barrels per day achieved by 1978. The pipeline is 800 miles long from Prudhoe Bay to Valdez. In 1968 its cost was estimated at $900 million. Cost to completion is currently set at $5.982 billion. It has been estimated that by 2002 the estimated 10 billion barrels of reserve will be consumed.

There is currently doubt that the U.S. West Coast demand can absorb the expected maximum production from Prudhoe Bay which may cause production to be slowed or for alternate distribution to be introduced.

Reserve estimates that are recoverable are the subject of frequent revision largely as the basis for planning for energy independence.** The following data is extracted from "The Economic Value of Ocean Resources to the United States," Committee on Commerce, December 1974.

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*Offshore, May 1975, p. 194.

**See also IPE, 1975.

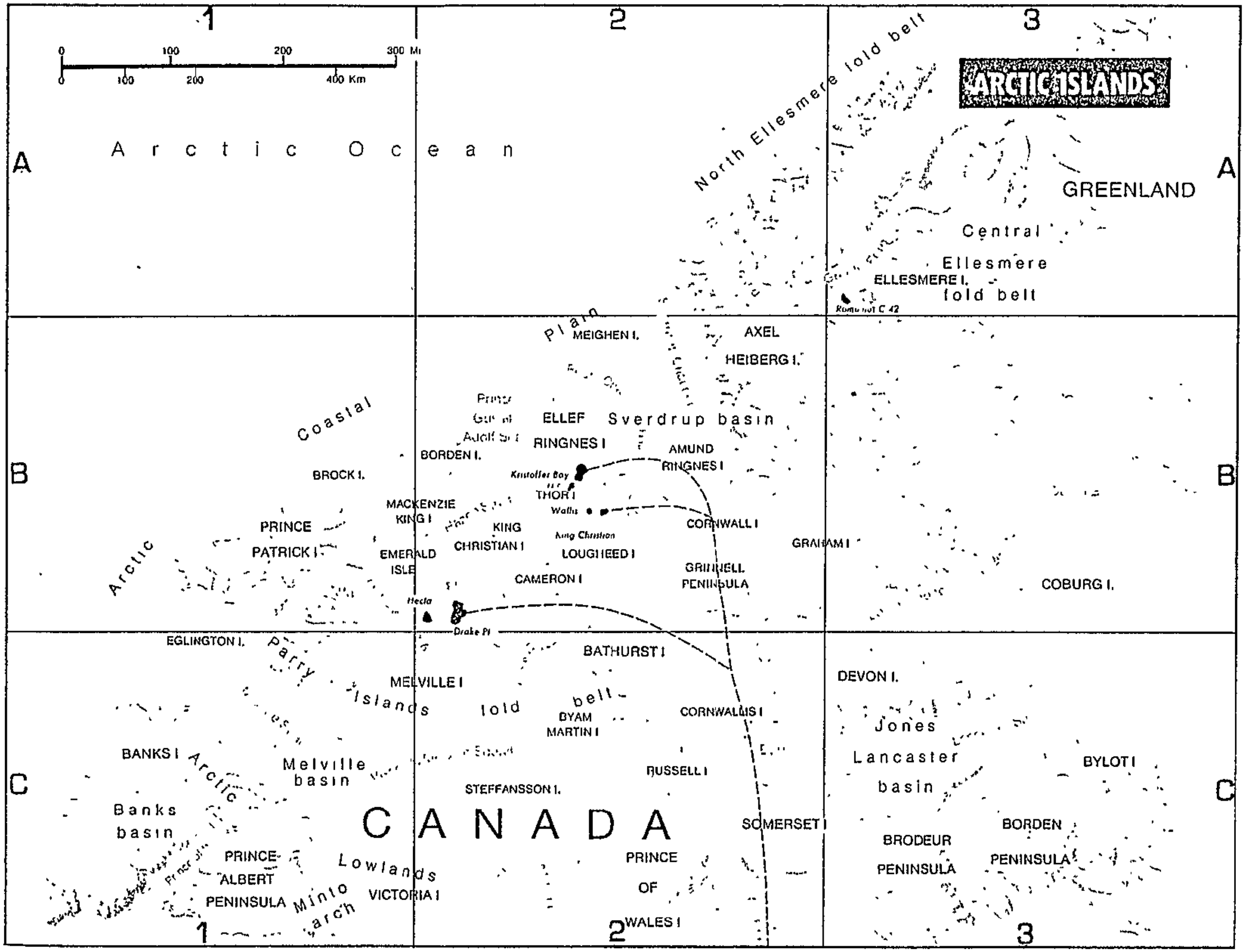

Figure 4.4 Map of the Arctic Islands

Up to the end of 1972 some 115 million barrels of oil and nearly 440 trillion cubic feet of natural gas have been produced in the United States, approximately 5 percent of each having come from offshore areas.

If those "recoverable" sources, undiscovered but believed to exist, are omitted, only 70 to 90 billion barrels of oil and 400 to 500 trillion cubic feet of gas are left to be produced in the United States, with 10 to 14 billion barrels of oil and 71 to 93 trillion cubic feet of gas offshore. These are the latest USGS estimates substantially reduced, particularly for offshore, from earlier estimates. The USGS also states, there are more undiscovered resources onshore than offshore but that offshore resource reserve share will grow as exploration gets underway. These estimates extend out to 200 meters of water.

There is a deliberate program to accelerate federal offshore leasing but production in the immediate future will be restrained by shortages of manpower, drilling vessels and equipment.

In 1972 the National Petroleum Council (NPC) made a detailed projection of production taking into account drilling rates, finding rates, Alaskan North Slope production and return on investment. These projections are shown below:

Oil	11.1	9.6 - 10.2	8.9 - 13.6	10.4 - 15.5	million barrels/day
Gas	22.3	21.8 - 23.7	17.3 - 26.1	15. - 31.9	trillion cubic feet

This projection used offshore resource estimates well beyond the latest USGS revision quoted above.

The Bureau of Mines in 1973 offered a projection for offshore production as follows:

1970 base	588 million barrels
1985	962 million barrels

These projections have been extended by the staff of the Assistant Secretary of Interior for Mineral Resources, as follows:

Year	% of U.S. Total	Millions of Barrels
1970	16.7	
1973	19.5	
1985	23.6	
2000	29.9	1045

Similar projections are made for natural gas production but are not reported here. The report also suggests that it is doubtful that the long-term relative price of either gas or oil will rise much above the values set in 1974. Thus, the report sets a reasonable long-term estimate for oil at $10 per barrel and for natural gas at $0.80 per cubic foot.

4.3 Factors in the Transportation of Arctic Oil and Gas by Surface Ship

This section provides descriptive information about ice conditions along various possible shipping routes by which oil and gas can be transported from Canadian Arctic sources. Figure 4.5 shows the general placement of the transit being considered.

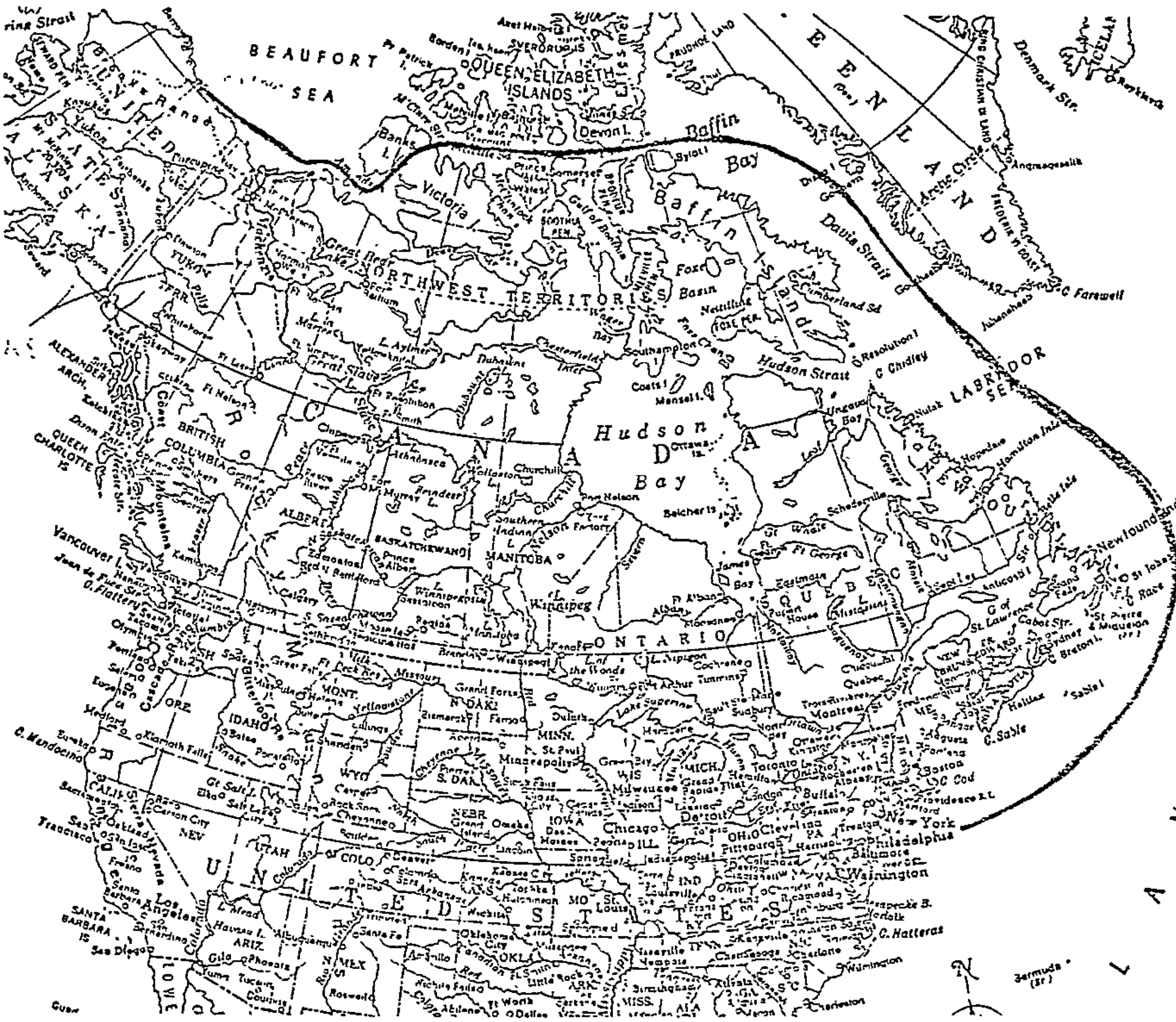

Figure 4.5 Canadian Arctic Transit Routes

The nature and frequency of ice reconnaissance and weather information requirements varies considerably in different parts of the Arctic. The benefit obtained from daily ice reconnaissance depends on destination or starting point within the Arctic, the time of year, the type of ship being used and the rapidity of change of ice conditions along the route.

An increase in Arctic inbound shipping can be expected if offshore activity increases. Massive tonnages of pipe will have to be shipped into the Arctic if any of the proposed major oil or gas pipelines are built. Of additional significance from both an economic and environmental viewpoint, is the possibility of shipment of resources out of the Arctic.

This section will consider the ice conditions likely to be encountered at various times of the year by ship transits from Canadian offshore areas from which petroleum might be shipped eastward. They are considered briefly to gain some insight into the types of ships that may be used, the type of ice information needed and the reduction in delays that may be achieved through improved ice forecasting. Maps relating to the regions involved appear earlier in the text.

Arctic Islands oil and gas could be transported by pipeline to Devon or Ellesmere Islands and from there by surface ship to East Coast markets. Possible departure points include Jones Sound (south coast of Ellesmere) and Radstock Bay (good

conditions for a pipeline to here) on Devon Island. Alternatively, more powerful surface ships could go directly to the Sverdrup Basin and transport petroleum from one or more of the islands. The best oil prospect Panarctic has found in seven years (and 100 wells) of active exploration in the Islands is at Cameron Island. Although the initial strike there flowed only 500 barrels per day, Panarctic is hoping for about 500 million barrels of proven reserves on the island. Panarctic officials are considering year-round tanker shipping directly from Cameron Island (see Figure 4.4). Liquified natural has could also be transported by tanker either from Devon Island or from Drake Point on Melville Island where proven reserves are already more than 5 trillion cubic feet. Beaufort Sea oil could be shipped by ice-breaking tanker from a terminal, e.g., Hershel Island in the Beaufort Sea, through the Northwest Passage to East Coast ports. Descriptions of ice conditions faced by ships transitting the Arctic passage are given below, from different departure regions.

4.3.1 Jones Sound and Radstock Bay

Shipping from the south coast of Devon or Ellesmere Islands involves transit through Baffin Bay and Davis Strait. These water bodies are subject to strong winds and current. Ice conditions are very dynamic year-round and the ice reacts quickly to wind changes. From hour-to-hour conditions can be such as to create leads which a ship could take advantage of or create pressure points hindering a ship's progress. The May

1970 voyage of the Manhattan was beset for days near Disco Island (off the Greenland coast) by ice driven across the bay by a northwest wind and held onto the Greenland coast under pressure. For about nine months of the year in Baffin Bay there is enough ice that under certain conditions of wind and current would present problems for a ship. Strong winds over an extended period of time can create ice pressure forcing all movement by shipping to stop. The driving pack, under pressure on an exposed coast, can sweep a ship along with it and deposit her on the shore. Although first-year ice predominates in Baffin Bay, there may also be floes 15 or more feet thick. High pressure fields and heavy ridging (10 per nautical mile) is possible because of the moving ice, strong winds, large water bodies and hence, long fetches.

Optimum route selection will involve making use of open areas, leads, flaws and other weak points or discontinuities in the ice. Optimum transit speeds can be maintained by a knowledge of iceberg distribution on route. Large tankers such as the Manhattan have great strength but sacrifice something in maneuverability. In order to maintain acceptable speeds and keep on schedule, particularly under the conditions of low visibility (fog) which are frequent along this route, bulk carriers will have to have a positive knowledge of what lies ahead. In her 1969 Arctic voyage, the Manhattan was preceeded in her voyage through the iceberg-infested waters of Baffin Bay by the ice-breaker John A. MacDonald which delineated

a path for her to follow. At various stages no point on the horizon was visible because of icebergs.

Since wind has a far greater effect on the movement of ice than currents, clearly, a reliable forecast combined with knowledge of present ice conditions could indicate ice movement and possible pressure points and would be of great value in routing.

4.3.2 Beaufort Sea (Hershel Island)

Shipment of Beaufort Sea oil to eastern markets involves use of the Northwest Passage. Conditions are highly variable along this route. East of Resolute Island, the ice is churning year-round and the area is quite sensitive to change--frequent ice surveillance is, therefore, required all year. Ice conditions in Lancaster Sound have similarities with those of Baffin Bay. Icebergs drift in in the summer and leads and pressure ridges (with frequency about 10 per nautical mile) are formed in the winter.

West of Resolute through Prince of Wales Strait, from February to May, reported ice information indicates the likelihood of small change during the period. This should be qualified, however, by noting that the impact of tanker traffic could convert a relatively static situation into a chaotic one (the effect is not known at the present time). However, during the Manhattan voyage when there was pressure on the ice, the water wake behind the ship disappeared within 100 yards of the ship so there was no visible evidence of

her passing. The ice in Viscount Melville Sound is the heaviest along the Northwest Passage route. Ridge frequency is 15 to 20 per nautical mile and ridge heights of 20 or more feet are found. Significant ice movement can be expected in this area from July through December. In addition to providing information on distribution and movement of ice during the summer, ice reconnaissance would show the pattern of freeze-up in the fall and the impending pattern of breakup itself. For about seven months of the year frequent surveillance will be required in this area. During the breakup period, old ice moves down from the north in floes 12 to 15 feet thick. These may plug the entrance to Prince of Wales Strait. This condition and an open route through M'Clure Strait could sometimes make it the preferred passage in September and October. After freeze-up, when new ice surrounds multi-year ice, it is desirable to distinguish between them. The multi-year ice could be 12 feet thick and first-year ice 3 feet. In addition, it is essential to identify ice island fragments which may rise a few feet above the surrounding ice but can be extremely thick, e.g., 12 feet above and 120 feet below. For ships operating in the Arctic, the shortest route is frequently not the fastest and if a ship has knowledge of old ice and ice islands ahead, it can detour or go a completely different route with considerable time savings. Frequency, size and orientation to track pressure ridges are all important, and optimum route selection can save time. Mo-

mentum is important and if a ship cannot maintain her momentum in passing through a high density region of pressure ridges, she may be stopped and require assistance.

The Beaufort Sea has dynamic year-round ice conditions like Baffin Bay. Here, changes in wind velocity and direction have a dramatic and extremely rapid influence on ice conditions. Ridging is severe and frequent (approximately 15 per nautical mile). A heavy shear ridge can exist between the shorefast ice and the moving Beaufort Sea ice. Frequent ice forecasting is required for year-round activity in this area. One risk of damage to ships in the Arctic comes from running aground. Although this is most likely to occur in uncharted waters, a driving pack under pressure could drive a ship aground. Ice and weather forecasting will be important in shallow water areas, particularly near a terminal (e.g., Hershel Island in the Beaufort Sea) when the ship wants to stay in a narrow channel to get into refuge.

Mass and momentum are extremely effective in ice so that 150, 000 to 250,000 dwt vessels are expected to be used if petroleum is shipped out of the Arctic. They might travel in pairs but this creates scheduling problems at loading terminals. On the Manhattan voyage there were 25 occasions when she required assistance of her ice-breaker escorts. Although it was felt that most of these occasions sould have been avoided with a more powerful ship, it was also felt that skillful shiphandling together with excellent

ice forecasting will be required for efficient year-round navigation. In addition to besetments in hummocked old ice floes, the Manhattan experienced difficulty in the Beaufort Sea in an area where heavy snow turned the ice into a heavy sludgy consistency. Also pancake ice in one area, not more than 10 inches thick, stuck to the ship and piled up ahead of her until it brought her to a standstill. Ice-breaker assistance was required.

4.4 Remote Sensing Benefits to Arctic Oil and Gas Transport

The description of ice conditions to be encountered by ships transporting reserves out of the Arctic has been given to indicate the utility of ice forecasting. It is difficult to estimate the expected improvement in operational efficiency that could result as this varies with the time of year and design of ship. Clearly, a Class 6 ice-breaking tanker will experience more difficulty in winter in passing from Lancaster Sound through Baffin Bay than a Class 8 (or 10) tanker coming from Hershel Island or Cameron Island and built to traverse the heavy ice of Viscount Melville Sound. On the average, it has been estimated, however, that ice forecasting provided by remote sensing could save two to three days (per voyage) for ships coming from the Beaufort Sea (three days for half the year when conditions are very dynamic), two days for ships coming from Cameron Island or Ellef Ringnes since there are choices of routes possible, and one day for ships

coming from Jones Sound and the south coast of Ellesmere. These savings have been discussed with Captain T. C. Pullen who was on board the Manhattan. It is estimated that a SEASAT or equivalent operational satellite system giving extent and movement of ice, leads, ice islands and icebergs (with coverage twice per day) would achieve about 75 percent of these benefits under all weather conditions. Some information on pressure ridges, ice age and type and snow is also almost certain but uncertainties about the quality of information in these areas will only be resolved when satellite data becomes available. Further studies are in progress to relate delay times to ice conditions and to ship design.

As the benefits derived from remote sensing depend on the shipping traffic, the values are in doubt until decisions regarding the mode of transportation are made. It is probable that eastern offshore oil and gas (in liquefied form) will be transported by surface ship to East Coast markets. It is possible that Arctic Islands oil will also be transported by surface tanker. Less attractive but also possible is the transport of liquefied natural gas from the Arctic Islands.

Transportation of oil from the Beaufort Sea is also a possibility but less likely is view of the multi-year ice conditions. The severity of the risk of oil spills to the delicate Arctic ecology has prompted many to dismiss surface shipping as a possible mode of transport.

4.4.1 Applicability of SEASAT Instruments to Ice Reconnaissance

SEASAT-A will not be able to observe the entire Northwest Passage because of its 108-degree orbit inclination. Its northernmost coverage reaches to about 72° N latitude. This will allow it to see the entire shear zone along the northern coast of Alaska. The regular synoptic observation of ice information from this area will be of great value of exploratory drilling and supply shipping. The SEASAT operational system will likely be in operation well before the expected opening of the Northwest Passage. However, in contrast to the 72° N latitude coverage of SEASAT-A, the near polar orbit of an operational SEASAT will provide coverage up to at least 76 degrees and will be useful for navigation along this entire Arctic Islands region, and thereby, considerably enhance the value of SEASAT for general ice reconnaissance.

All the SEASAT instruments have possible applications to the remote observation of ice. Only one, however, has good enough resolution to be of definite utility for routing ships: this is the Synthetic Aperture Radar (SAR). Many investigators have experimented with airborne SARs for remote sensing of ice. The sum of their experience indicates that this instrument has great potential for gathering many types of ice information. There is no question that SAR images contain valuable qualitative information about ice. So far, however, few quantitative results have been obtained.

For example, it is known that ice surface roughness is correlated with image brightness but no specific numerical relationship has yet been determined for any particular radar. It is expected that, during the next several years, methods for quantizing and calibrating the data can be developed. Even at the present state-of-the-art, much valuable information is available from SAR imagery.

Optical imagery may contain more detailed information about ice than radar but Arctic weather conditions demand a sensor which can penetrate cloud cover. The SAR's ability to see through clouds and even light precipitation makes it ideally suited to the Arctic. <u>This means that SEASAT has a unique capability for Arctic ice reconnaissance</u>.

Table 4.1 shows a list of ice descriptors needed for good ice forecasting and navigation. It can be seen from the second column that while SEASAT probably cannot supply every piece of information that an Arctic ship captain would desire, it certainly can supply him with many facts which will be of great assistance.

Knowing the locations and orientations of leads (open water areas), for example, can greatly reduce ship travel times. Clearly, sailing along a lead is preferable to breaking ice. In addition to this, orientation and spacing of leads show the "grain" of the ice pack and so indicate the easiest direction of passage, even if the ship track is not actually through open water.

Table 4.1 Ice Characteristics Needed for Forecasting and Navigation

Ice Description	Is SEASAT Applicable?	Comments
Leads (open water)	yes	Leads are visible on SAR. Ships should sail in them or parallel to them.
Ice Surface Roughness	yes	Knowing these parameters together with wind velocity, ice movement can be predicted. Surface roughness correlates well with SAR image brightness.
Ice Internal Strain	yes	Strain is measurable by comparing time-sequential SAR images.
Ice Bottom Roughness	no	When good models are developed bottom roughness may not be required.
Ice Thickness	indirectly	There is no obvious way to measure thickness directly with SEASAT. Some information is available indirectly.
Pressure Ridges		These are belts of highly deformed ice which are hard to break through. SAR imagery shows their orientation and spacing.
Orientation	yes	
Spacing	yes	
Thickness	no	
Distribution of Multi-year vs. First-year Ice	yes	Detectable from SAR images. Multi-year ice is much harder to sail through than first-year ice.
Snow Depth over Ice	doubtful	This affects the coefficient of friction between ice and ship side.
Iceberg Locations	yes	Visible on SAR images.

Leads are clearly visible as black regions on an SAR image because the relatively smooth surface of water has very low specular reflectivity.

At the wavelengths used by SEASAT's sensors, radiation is rapidly attenuated as it penetrates sea ice. Virtually all the return is from the top surface of the ice. Therefore, there does not appear to be any way to measure ice thickness directly using SEASAT's instruments. Thickness information can be obtained indirectly, however. For example, first-year ice is thinner than multi-year ice, and these two types of ice can be distinguished by their differing surface roughness. First-year ice is relatively smooth, and thus, gives much less radar return than the rough, broken surface of multi-year ice. Multi-year ice, besides being thicker than first-year ice, is very tough and difficult to break through. It follows that differentiating between these two types of ice is very important for navigation.

Pressure ridges are belts of highly deformed ice formed by internal stresses in the ice. Along pressure ridges, ice extends upward in a high "sail" and down in a deep "keel"; overall pressure ridge heights of 50 feet are not uncommon and 150-foot ridges have been encountered. Horizontal thickness can be 5 to 10 miles and lengths can extend to 100 miles or more. Obviously, this kind of ice is to be avoided. SEASAT data is useful since pressure ridges show up as bright lines on

SAR images. The vertical thickness cannot be measured but locations and orientations are definitely available.

The depth of snow lying on top of the ice affects the coefficient of friction between the ice and the hull of a ship passing through it. Thus, knowledge of snow depth would help in predicting the difficulty of passage along a given route. Unfortunately, SEASAT probably cannot supply this information.

Icebergs are visible on SAR imagery. The requirements for monitoring and predicting the movement of icebergs was investigated in an earlier SEASAT applications case study by Batelle.* This study concerned the utility of SEASAT to the U.S. Coast Guard in the conduct of its International Ice Patrol Program. As indicated in this earlier study, SEASAT should make it possible to track icebergs and predict their movements so that ships can be routed away from them.

The models necessary to forecast the movement of ice are not fully developed nor in operational use yet. It appears that the important parameters of such forecasting models are the wind velocity, the ice top surface roughness, bottom surface roughness and internal strain. Top surface roughness determines the driving force exerted on the ice by the wind. Bottom surface roughness affects the drag force created as the ice moves through the water. Internal strain is important because part of the applied forces will go toward making the pack

*SEASAT Economic Assessment, October 1974, pp. 7-60.

converge or diverge rather than drift as a whole. SEASAT data should accelerate the arduous process of developing and calibrating such a model.

Ice surface roughness should be measurable since it is the parameter which determines SAR image brightness. The internal strain in the ice should be obtainable by measuring the relative movement of features on SAR images. When two features move toward one another, for example, there is a compressive strain developing in the region between them. The roughness of the ice bottom surface will not be measureable from SEASAT. However, when all the factors affecting ice movement become fully understood, it may be that forecasts can be made without knowing this parameter.

To summarize, SEASAT will not be able to measure every useful ice parameter but it will be able to supply a great deal of valuable information. Because it can see through clouds with good resolution, the SAR is probably the best single instrument for ice monitoring. This puts SEASAT in a unique position among currently planned satellites to make a major contribution to an ice reconnaissance system for Arctic shipping.

4.4.2 The Exclusive Contribution of SEASAT

SEASAT sensor technology, primarily the SAR, provides radar imagery of the ice region.

The quality both of the imagery and of its dissemination to all tankers involved, in all types of operating

weather, will evidently determine the importance of SEASAT in facilitating transits through the ice of the Northwest Passage. This transit is indicated approximately on the map, Figure 4.6.

While SAR ice data interpretation is today somewhat devoid of quantitative results, it can be expected that this condition will have improved considerably by 1985, with the results of an active program of aircraft experimentation and the analysis of data from SEASAT-A.

Navigation of the tankers requires avoidance of pressure ridges and polar or multi-year ice. A pressure ridge can extend for more than 100 miles and be from 5 to 10 miles across with a thickness of up to 147 feet. Polar ice is such that a thickness of 3 feet of it will stop most current ice-breakers. It can be up to 12 feet thick. Hence, the imagery could be very significant in identifying regions to stay away from although ice thickness which is not available would seem to be an important parameter. Each ship of a given weight and power will presumably have an ice penetration thickness beyond which it can be expected to have difficulty.

The Arctic polar basin pack ice is perennial, occupying almost all the space between the North Pole and the North American and Eurasian coasts. The ice area is a minimum in August with a diameter of about 1900 miles and is a maximum in February with a diameter of about 2500 miles. Closings and openings of the pack ice are induced by wind stress and ocean currents, leads occurring when the ice is open.

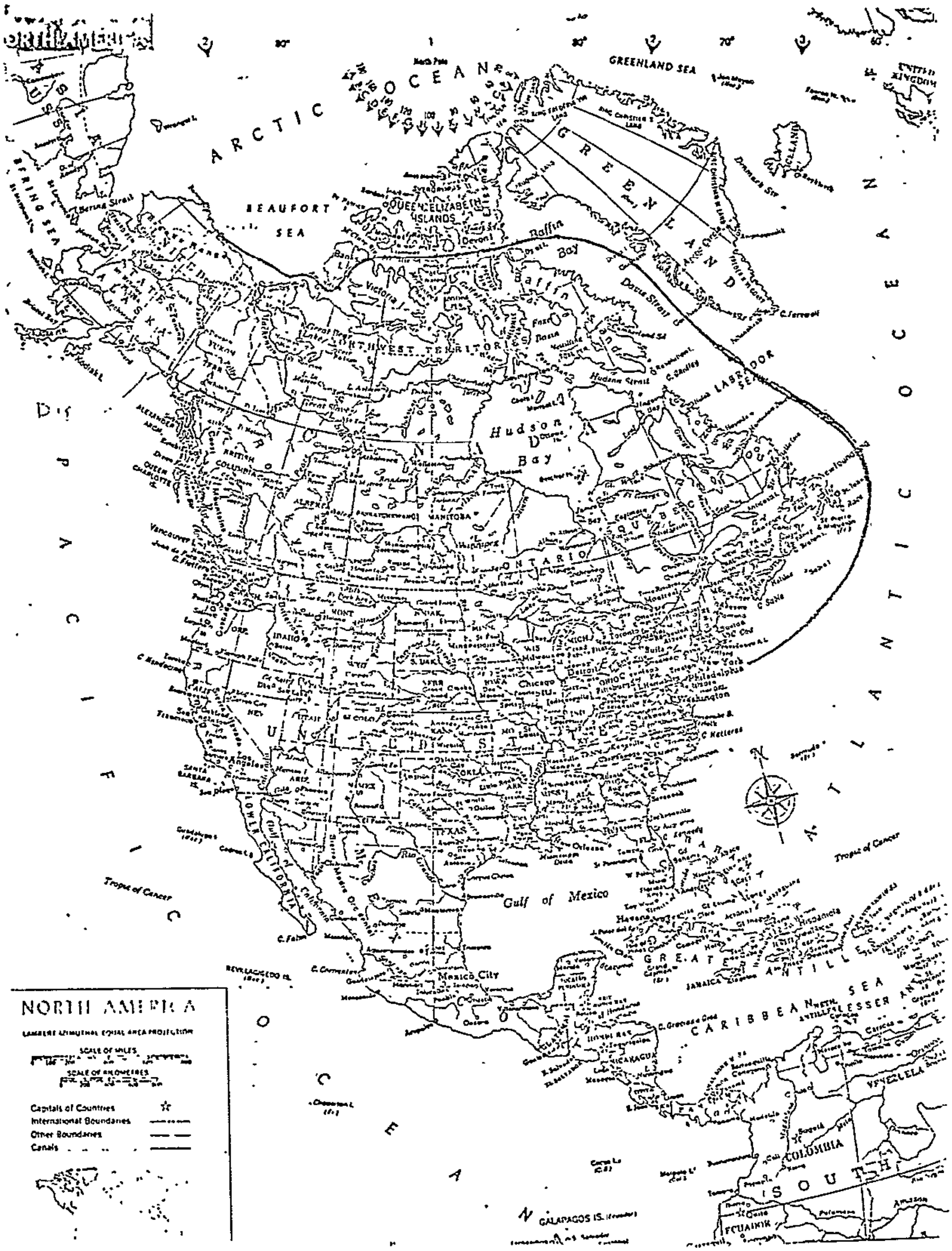

Figure 4.6 Canadian Arctic Transit Routes

Ship transit delays are assumed to occur when a ship's forward progress is arrested by ice that it cannot penetrate, or by slush or pancakes which pile up to prevent ship forward motion.

The ships under discussion, approximately 250,000 dwt tankers, evidently have a great advantage in terms of momentum but they are not particularly maneuverable. This implies that an error in knowledge of ice thickness could result in a ship becoming well entangled with the ice.

Actual experience in navigating through Arctic polar ice is very limited, and a great deal needs to be learned to relate delaying ice conditions to the characteristics of the design of ships.

For completeness, in this case study an estimate of SEASAT's exclusive contribution to solving Arctic ice navigational problems to minimize transit delays is required, and subsequently, a judgmental estimate is made.

Ice leads would be most likely in the current ice-breaking season from June to November. In the other six months of the year ice thickness of new ice would be important to know. New ice can be 6 to 10 feet thick.

Navigational assistance must take into consideration ice drift, a movement of 0.3 to 0.5 knots under the influence of dominant winds, to satisfy navigational passage prediction, and some appropriate data can be provided by the SAR.

Assuming that ice imagery from the SAR during the

period before 1985 will be the subject of study and experimentation which will clarify the interpretation of the utility of the ice imagery to navigation, and that dissemination of this data will be adequate, a judgmental estimate will be made of the operational SEASAT's exclusive contribution to the benefits. The following assumptions will be made:

	Characteristics	Weight
1.	• leads can always be identified	
	• leads are useful 50% of the year	
	• travel in leads occurs 45% of the time in the summer season	0.450
	• thickness of the ice is required 55% of the time	
	• SEASAT's indirect thickness measurement capability has a 20% utility	0.110
	Seasonal weight 0.56 x 0.5 =	0.28
2.	• in the winter season pressure ridges and polar ice are a problem and it will be assumed that they can always be located, but thickness is still only a 20% utility for new ice	0.2
3.	• in the winter season it will be assumed also that 15% of the time there is very heavy precipitation which degrades the SAR data.	
	Seasonal weight 0.5 x 0.2 x 0.85 =	0.08

For each year, judgmentally, SEASAT can therefore exclusively contribute 0.28 + 0.08 = 0.36 of the total of any annual benefit calculated.

5. THE WESTERN ARCTIC CASE STUDY

The Western Arctic Case Study is founded on an Arctic Marine Commerce Study carried out by the Arctic Institute of North America (AINA) for MARAD, published in August 1973.*

The AINA study projects an East Coast demand for Alaskan oil at 450 million barrels per year by 1985 and 792 million barrels per year by 2000. With an assumed linear growth the integrated demand for oil between 1992 and 2000 is 6.3 billion barrels. It is not expected that this demand could be satisfied by Arctic discoveries until 1992. Between 1985 and 1992, presumably, the demand would be satisfied by oil imports. In 1973 oil imports amounted to 1.184 billion barrels.

Current U.S. reserves to production ratio are about 11:1 which is low compared to a more usual ratio of about 30:1. Thus, the projected production must be supported by approximate discovered reserves of from 8 billion barrels to 21 billion barrels.

After study, the AINA report envisages, from comparative transportation analysis, that tanker transport via

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*Arctic Institute of North America, <u>Arctic Marine Commerce Study</u>. Prepared for the U.S. Maritime Administration, August 1973. NTIS report numbers COM-73-12001, 12002, 12003.

**Statistical Abstract, No. 856, pp. 5, 6.

the Northwest Passage will be the least expensive mode of moving North Slope oil to the East Coast, compared to a Trans-Canada to U.S. pipeline. The AINA study indicates that 245,000 dwt Arctic tankers can be operated for this transit each with a capacity of about 1.6 million barrels. The study envisages a fleet of from 21 to 33 such tankers depending on whether or not there will be trans-shipment of oil. With these assumptions for this projected operation the total number of laden and empty transits is estimated to be 7900, over the years 1992 to 2000. Each such transit will be facilitated by useful ice lead navigational information. With something on the order of 2.4 voyages per day as the traffic volume, considerable logistic support is visualized for the operation so that the operational SEASAT ice lead sensing is only one part of the total contribution to the operations activities.

Bearing in mind the conjectural nature of this operation and that for the near future the principle unknowns in Arctic oil are the rates at which money, men and materials can be made available for the necessary exploration and development and that for the distant future the principle question is how much of a production effort can the potential oil reserves support, there is a large measure of uncertainty compounded by the now diminished tax incentives and an uncertain oil and gas import policy. The timing with which such an operation could come into being seems very reasonable, both from a technology development point of view and the general expectation of the

difficulty of finding, developing and producing recoverable Arctic oil. Figure 5.1 is from the AINA report and represents a consensus of expert opinion relating to Arctic marine commerce technology development. Also shown in this figure are the launch dates for SEASAT-A (1978), and the date of the operational SEASAT program (1985) used in this economic assessment. The relationship between the SEASAT dates and the development of the Arctic transportation capability is apparent. If the development of the Arctic resources and transportation occurs on or near the schedule shown, it is important that the capability to improve ice and weather forecasting in the Arctic regions occur on a somewhat matching schedule. In order to be conservative, the benefits from operational SEASAT data to the transportation of Arctic resources are considered to commence in 1992. As shown in Figure 5.1, there are significant benefits associated with exploration, development and production that can occur in the period from 1985 to 1992.

The last event to occur in this consensus is the opening of a polar shipping route and, as previously stated, this time is reasonably consistent with the possibility of producing Arctic oil, so that the tanker shipment could occur at that time if the required tanker fleet was available.

In summary, the case study parameters appear to be reasonable. Based upon oil deposit estimates and preliminary findings, there is evidently sufficient oil to be recovered to provide the reserves appropriate to the postulated pro-

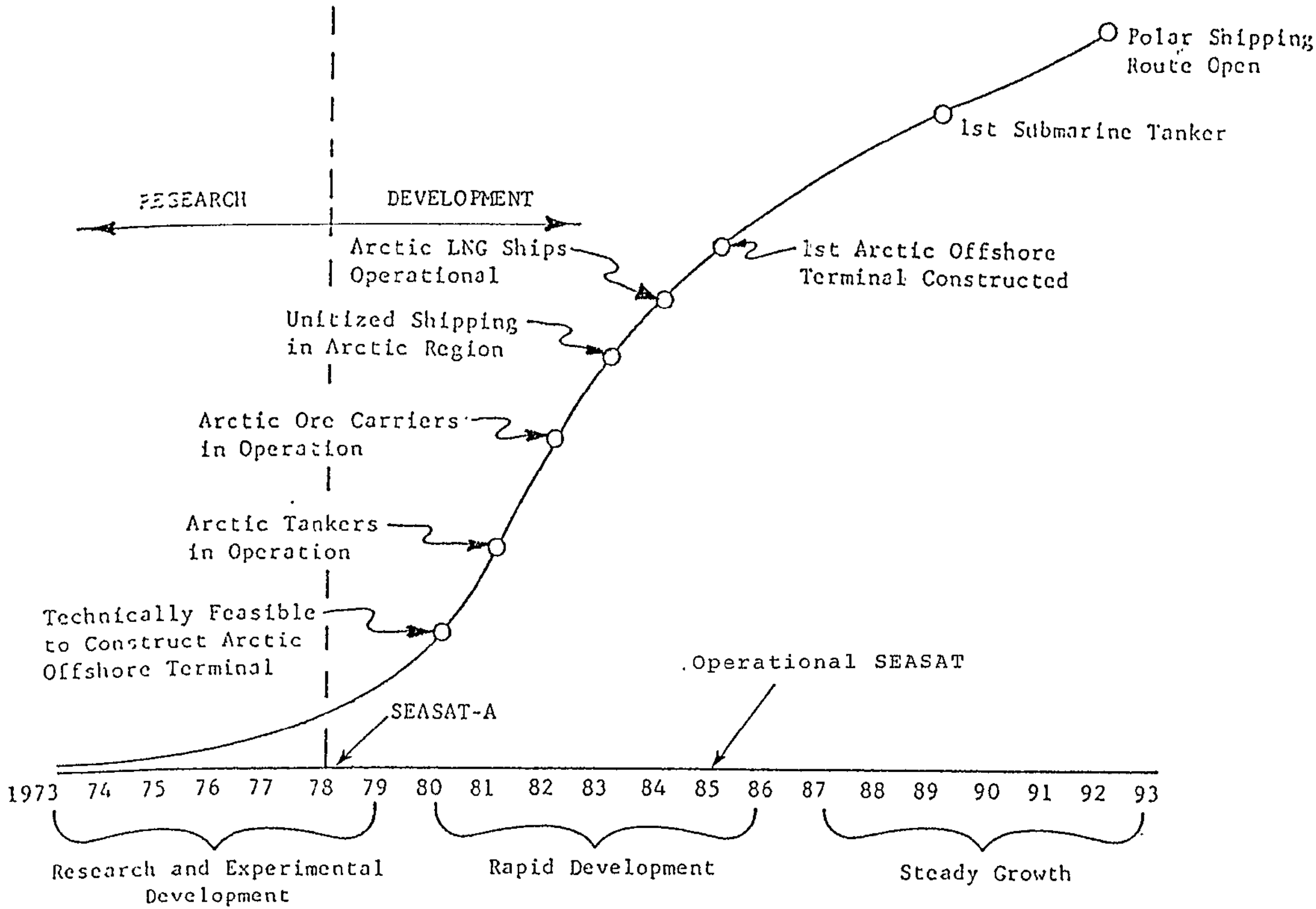

Figure 5.1 Technology Forecast for Arctic Offshore Activities with SEASAT Schedule Superimposed. Vertical Axis in Arbitrary Units. (From Arctic Marine Commerce Study. Written by: AINA, Sponsored by: Maritime Administration, 1973)

duction. It is not necessarily evident that the oil quantities postulated will originate in the Alaskan North Slope region onshore but it seems reasonable to postulate that they can originate in the Arctic regions in general. This is so in spite of the fact that there is much upsurge in exploratory drilling in offshore Alaska.*

The time at which production could occur, i.e., 1992 and later, seems to be in reasonable accord with estimates that can be made to develop the expertise in producing onshore and offshore oil in the Arctic regions, within the complexity of the technology and its applications. Transportation of produced oil remains a subject of considerable controversy. Pipelines are recognized as inexpensive, efficient and potentially environmentally sound means for moving both liquid and gaseous hydrocarbons. Delays are to be expected and scrutiny will be thorough to show that they are both environmentally safe and economically viable. Their capacity can reasonably be designed to be sufficient to handle anticipated increases in domestic production. Tankers operating in the dangerous waters of the Northwest Passage presumably can also be economically viable. However, with large amounts of traffic, accidents and oil spills can be expected which present specialized difficulties in the ice environment ranging from routine in open water to next to technologically impossible

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*Offshore, March 1975, p. 110.

if oil is absorbed by the ice or locked into growing ice.*

U.S. energy conservation measures can be expected to reach fruition by 1985, if current policies and actions are maintained. It is considered that oil and gas will continue to supply a major part of the energy needs of the United States through 2000 as a result of the lead time needed to plan, organize, construct, and put into operation alternate sources of energy. Beyond this time, rising demand and alternate sources make it very difficult to forecast a supply need on the U.S. East Coast for Alaskan oil.

Major amounts of capital investment will be required to reverse current declines in domestic production. Whereas, in the United States capital requires per well was about $100,000, North Slope development will be in the millions of dollars per well. Offshore production will cost tens or hundreds of millions of dollars. The drilling rate required must also increase in proportion to advancing consumption, and in the hostile Arctic environment specialized drilling equipment is needed, as is specialized production equipment. Specialized experimental equipment such as an ice cutting rig and under-sea ice diving apparatus is being tested by the oil companies.**

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*<u>Offshore</u>, March 1975, p. 133.

**<u>Offshore</u>, January 1975, p. 33 and March 1975, p. 109.

5.1 Derivation of Western Arctic Benefits

During the nine years of operation from 1992 to 2000, the ice-breaking tankers will complete 7900 transits by the Northwest Passage in moving oil from the Arctic oil sources to the East Coast.

SEASAT data is postulated as being able to contribute to a reduction of each transit by a given amount of time which, on the basis of daily operating costs, will reduce the oil transportation costs accordingly. SEASAT instrumentation will be capable of detecting leads in the ice to facilitate navigation through forecasting of their position.

The benefit parameters to be considered are the following:

1. expected tanker daily operating costs
2. the number of transit days per transit that can be saved through ice lead navigation
3. the amount of oil that will actually be shipped (from 1992 to 2000).

Citing these parameters only assumes that the choice of a 245,000 dwt tanker for this application, including its loading and unloading requirements as an integrated operation, is most economical irrespective of the hull structure and the ice-breaking capacity.

Tanker construction costs vary greatly with the type of vessel and where it is constructed. Offshore, March 1975, p. 13, quoted a contract for two 150,000 dwt tankers that will

cost more than $120 million. The SEASAT preliminary economic assessment, October 1974, p. 5-5, quotes costs for three 225,000 dwt tankers whose construction will cost between $57.3 million and $70.6 million by the time they are completed in 1976. Employing a rule of thumb that daily operating costs are about 1/10 of 1 percent of the capital costs would indicate daily operating costs for a 245,000 dwt tanker to be in the range of $57,000 to $71,000. The range considered for benefit estimates will be $50,000 to $75,000 per day.

Expert opinion from experienced ship captains, who have commanded in the Arctic, is that better ice condition information could reduce transit times by 25 percent.* The Northwest Passage transit is typically variable from 30 to 10 or 11 days depending on the time of year. Thus, improved ice condition information would save from 2.5 to 7.5 days for each transit.

Ice condition information improvement can therefore provide cost savings or benefits varying from $125,000 to $562,500 per transit, not all of which can be allocated to SEASAT.

It is difficult to foresee what the minimum amount of oil that would be shipped from the American Arctic to the East Coast would be between 1992 and 2000.

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*Clough, D. J., and A. K. McQuillan, "Economic Benefits of Sea Ice Remote Sensing Systems." Submitted to INFOR Journal, January 3, 1974, Revised April 4, 1974.

It is currently estimated that when all parameters are considered, it is economically viable to produce from a reserve of 5 billion barrels. The annual production from such a reserve would be from 5/11 billion barrels to 5/30 billion barrels depending on the reserve to production ratio. Thus, a minimum production would vary from 0.46 billion barrels per annum to 0.17 billion barrels per annum so that the total shipment over nine years would vary from 1.53 billion barrels to 4.14 billion barrels. The 1.53 billion barrels of oil is estimated as a minimum for pipeline shipment because of the transportation capital and operating costs associated with the estimated 5 billion barrels of a viable economic reserve. It is unknown at this time if this estimated minimum for pipeline transit will also apply for tanker shipment, particularly one that could be subsidized.

It will be assumed as reasonable, however, that the total oil shipment from the Arctic to the East Coast would be between 1.5 and 6.3 billion barrels. On the average then, the number of annual transits would vary between 209 and 878.

The annual benefits to such an operation would then vary from

$$209 \times \$125,000 = \$\ 26,13 \text{ million}$$

$$\text{to } 878 \times \$562,500 = \$493.88 \text{ million}$$

over the time interval from 1992 to 2000. This is a range of about 18.9:1 as a consequence of 0.57 to 2.41 transits per day and the variable daily operating costs of the tankers.

5.2 Integrated Benefits Exclusive to SEASAT

5.3 Western Arctic Benefits

The annual benefit range exclusive to SEASAT from ice reconnaissance through the Northwest Arctic Passage is estimated to range from $9.4 million to $177.8 million, i.e., 36 percent of the previously estimated benefit range, for the years from 1992 to 2000. These are benefits to an operational SEASAT. These benefits will be integrated at their present value in 1975 dollars by discounting back to the beginning of 1975. The benefit in 1992 is assumed to be available at the end of 1992, i.e., after 18 years and the benefit from 2000 is available after 26 years.

The integrated benefits exclusive to SEASAT are identified in the following table as a function of discount rate, factors for which are quoted.

Discount rate %	0	5	10	15
Factor	9	3.098	1.139	0.443
SEASAT exclusive integrated benefit range $1975 ($millions)	88-1600	29-551	11-203	4-79

6. THE EASTERN ARCTIC CASE STUDY

The Canada Centre for Remote Sensing has studied the problem of petroleum resource shipments from the Canadian Arctic eastward through the Northwest Arctic Passage.

The resources to be shipped are oil, liquified natural gas and hydrocarbons, all by appropriate tankers. The oil tankers have an assumed tonnage of 250,000 dwt although water depths in the Prince of Wales Strait might be considered too shallow for a ship of this size. Class 6 ice-breaking tankers are used in the Baffin Bay-Lancaster Sound region and Class 8 for the Arctic Islands and the Western Arctic. Their daily operating costs are estimated to be $77,000 and $85,000 respectively, increased by 20 percent from their 1972 values. Liquified natural gas and other hydrocarbons are moved in a Class 6 LNG tanker carrying 0.1 million cubic meters of LNG which has a daily operating cost of $89,000 and a Class 8, 250,000 dwt tanker at $85,000 per day for other petroleum products. These are thought to be suitable carriers for these resources.

Production from various sources, as quoted in Table 6.1, are consistent with 1974 projections of the Alberta Energy Resources Commission.* In Table 6.1, data

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*"Alberta Board's Brief Predicts End to Importing of Oil," The Leader-Post, Regina, April 5, 1974.

Table 6.1 Eastern Arctic Benefit Development

Resource Location	Resource	Annual Production		Number of Transits		Days Saved Per Transit	Days Saved Per Annum		Ship Daily Operating Costs $	Gross Annual Benefit ($ millions)		Average Annual Benefit ($ millions)
		1900	2000	1900	2000		1990	2000		1990	2000	
Baffin Bay Davis Str	oil	256 mbls*	365 mbls	292	148	0.5	146	209	77000	11.2	16.1	13.7
Arctic Islands	oil	91 mbls	219 mbls	104	250	1.5	156	375	85000	13.3	31.9	22.6
Beaufort Sea	oil	237 mbls	438 mbls	272	500	2.5	680	1250	85000	57.8	106.3	82.1
Arctic Islands	gas gas	6.0 m tons/ yr**	10.0 m tons/ yr	240	400	1.0	240	400	89000	21.4	35.6	28.5
Arctic Islands	hydro-carbons	3.0 m tons/ yr	6.0 m tons/ yr	24	48	1.5	36	72	85000	3.1	6.2	4.7
												151.6 Total Annual Average Benefit
												69.5 Total Annual Average Benefit Less Beaufort Sea Oil

* mbls = million barrels
** m tons/yr = million tons per year

is established from which benefits are computed and presented.

6.1 Alternate Sources of Benefits Not Considered

No benefits have been included for shipping oil and gas from the offshore East Coast-Labrador Sea areas to east refineries. The projected production of 1.06 million barrels of oil per day in 1990 would require 221, 250,000 dwt ship loads per year. The economic benefits would be small compared with those associated with the Arctic ice-infested waters. Heavy seas would not hamper the operation of these tankers and there is little choice of route open to them in any event. Some time savings would result from knowledge of the distribution of icebergs or other obstacles ahead, particularly in fog and in winter while ice conditions prevailed in the Gulf of St. Lawrence, thus providing faster steering times. Of more importance for both economic and environmental reasons could be storm forecasting allowing better and safer scheduling of loading and unloading operations.

Not included in the benefits presented here but considered in previous studies, are those associated with shipment of Mary River iron ore, Strathcona Sound and Little Cornwallis lead/zinc, and reduction of insurance premiums due to improved ice forecasting. These were found* to total more than $10 million annually. Also not included,

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*McQuillan, A. K. and D. J. Clough, "Benefits of Remote Sensing of Sea Ice." Research Report No. 73-3, December 1973.

are benefits associated with inbound shipping and seismic surveys.

Benefits from remote sensing assisted improvements in ice and weather forecasting may be largest in promoting safe operations and reducing environmental damage. The risks to wildlife are great in areas such as the Beaufort Sea and in Lancaster Sound where drilling will be done in 2500 feet of water.

6.2 Integrated Benefits Exclusive to SEASAT

The average annual benefits derived in Table 6.1 are aggregated from 1990 to 2000. The aggregated benefits over this period are discounted at the beginning of 1975. That is, 1990 benefits are discounted for 16 years and 2000 benefits are discounted for 26 years.

The aggregated benefits are tabulated in Table 6.2, as a function of discount rate with the aggregated discounted factors noted.

The benefits exclusive to SEASAT are based, as previously, on an estimated 36 percent contribution allocation to the factors provided by SEASAT's instrumentation.

On the average, the amount of oil to be shipped from Canadian Arctic sources is 803 million barrels per annum over the ten-year period. For such a shipment from production, the recoverable estimated reserves discovered would have to lie between 8.83 billion barrels and 24.09 billion barrels, based on reserves to production ratios

Table 6.2 Eastern Arctic Integrated Benefits

Discount percentage	0%	5%	10%	15%
Discount factor	10	3.9954	1.5547	0.6426
Integrated benefits ($ millions)	1520	607	236	98
Integrated benefits less Beaufort Sea benefits* ($ millions)	700	280	109	45
Integrated benefits exclusive to SEASAT ($ millions)	547	219	85	35
Integrated benefits less Beaufort Sea benefits exclusive to SEASAT* ($ millions)	252	101	39	16

*Beaufort Sea benefits may not be realized because of multi-year ice and ecological factors. The benefits are, however, included in the integrated benefits.

lying between 11 and 30:1. Some 72 billion barrels of oil are estimated to exist in these regions which implies discovery of 12.3 percent to 33.5 percent of the currently undiscovered oil by 1982-1985 depending on the estimated time from discovery to production. In the Arctic Islands this requirement, at the lower ratio of reserves to production, would be consistent with the Imperial Oil Ltd. estimate of a 2 billion barrel find but not at the higher ratio. There would not be this consistency

for the Beaufort Sea production or for the Baffin Bay-Davis Strait region production. It is not unreasonable to assume, however, that oil needs in Canada may diminish the importance of these.

7. COMBINED BENEFITS

The hypothetical operations that have formed the basis of the case studies presented could possibly both occur together.

This is that oil and gas development may evolve in the Alaskan North Slope, the Beaufort Sea-Mackenzie Delta, the Arctic Islands and the Baffin Bay-Davis Strait regions to give production quantities from all these regions that would be transported eastward for consumption.

Such an eventuality, with tankers employed for all shipments through the Arctic Northwest Passage, would result in the benefits of both case studies being arithmetically combined.

The combined, integrated, discounted benefits exclusive to SEASAT would then be as shown below, including Beaufort Sea oil.

Discount rate %	0	5	10	15
SEASAT exclusive integrated benefit range ($ million)	635-2147	248-770	96-228	39-114